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Measurement on the thermal conductivity of five saturated fatty acid ethyl esters components of biodiesel

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ABSTRACT

The utilization of biodiesel, which is considered as a renewable, biodegradable and clean-burning transportation fuel consisting of fatty acid alkyl esters, is a promising way to replace fossil fuels. Thermal conductivity is a very important thermophysical property of the biodiesel. In this work, the liquid thermal conductivity of five saturated fatty acid ethyl esters (ethyl myristate, ethyl laurate, ethyl caprate, ethyl caprylate and ethyl heptanoate) were measured with the temperature ranging within (290.64–393.88) K, (274.73–400.08) K, (270.00–400.44) K, (254.76–400.37) K, (250.38–393.46) K, respectively. The total relative standard uncertainty of the experimental results was estimated to be less than 2% and repeatability was better than ±0.5%. The experimental results of each substance were fitted as a function of temperature. The average absolute relative deviation and maximum absolute relative deviation between the experimental data and calculated results were 0.19% and 0.36% for ethyl myristate, 0.15% and 0.54% for ethyl laurate, 0.17% and 0.38% for ethyl caprate, 0.23% and 0.66% for ethyl caprylate, 0.19% and 0.52% for ethyl heptanoate, respectively.

1. Introduction

The fossil fuels are playing a crucial role in human progress and social improvement [1,2]. However, in recent decades, unabated combustion of the remaining reserves of fossil fuels are causing severe climate change such as global warming and air pollution [3–5]. In this case, other alternative energy resources are required to fulfill the energy consumption. Therefore, it has been the new focus of plenty of researchers in worldwide to develop dimethyl-ether, ethanol and biodiesel as renewable and alternative fuels [6–11].

Biodiesel, which comprises the saturated and unsaturated fatty acids esters from vegetables oils, animal fats or the hybrid of all of them, is considered as a sustainable fuel because it can be directly used in conventional diesel engine without significant modifications. The transesterification of triglycerides with ethanol and methanol can produce it, which is able to lead to the formation of fatty acid ethyl esters and methyl esters respectively [12]. By comparing with diesel fuels, biodiesels have many apparent advantages, such as being better biodegradability, non-toxic, non-sulfur content, higher cetane number, lower monoxide (CO), etc. [13,14]. In addition, it may reduce the emission levels of pollutant gases and contribute less to the greenhouse gas emissions. However, the thermophysical properties of both bio- and petroleum-based diesel are different due to the differences in chemical structure [15–18].

In recent years, the investigations on the thermophysical properties of biodiesel has been the topic of many studies [1,3,12,15–30]. For example, Yang and Wang (2018) conducted the experimental studies on the density and viscosity of binary mixtures containing the component of the biodiesel, namely methyl myristate, with higher alcohols, including 1-propanol, 1-butanol and 1-pentanol at atmospheric pressure from (303.15–333.15) K [12]. Gülüm and Bilgin (2017) performed studies on the viscosity and density of biodiesel-diesel blends' from theoretical and

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experimental perspectives [1]. Nikitin and Popov (2015 and 2016) measured the critical temperature and the critical pressures of some fatty acid methyl and ethyl esters [19–21]. Meng and Wang (2013) predicted the densities for three methyl ester biodiesels from room temperature to 523 K [22]. Shang et al. (2016) studied three ternary systems' phase behaviors at the temperature range within 493 k ~ 523 K [25]. Zhang and He (2016) used the Brillouin light scattering methods to measure the speed of sound in methyl caprate, methyl laurate and methyl myristate [26]. Nevertheless, the thermal conductivity of pure saturated fatty acid methyl/ethyl esters is scarce in the reports, and there is only one literature referred to the thermal conductivity of biodiesel constituent fluids. Perkins and Huber (2011) measured the thermal conductivity of methyl oleate and methyl linoleate in the liquid phase in a large temperature and pressure range [31]. In this work, the thermal conductivity of five fatty acid esters (ethyl myristate, ethyl laurate, ethyl caprate, ethyl caprylate and ethyl heptanoate) in liquid phase was measured.

2. Experimental section

2.1. Principle of experiment

Transient hot-wire method is considered to be one of the most accurate and reliable methods to measure thermal conductivity in liquid phase [32–34]. A single hot wire or two different length hot wires are usually optional. The method of two wires is more precise and can cancel the end effects, but the method of single wire has advantages in calculating the occurrence time of natural convection and heat transfer of thermal radiation, and the measuring circuit is much simpler. In this paper, we use the transient hot-wire instrument with one bare platinum wire to conduct the experiment. The basic working equation [34] is as follows:

$$\Delta T_{\mathrm{id}}(r_0, t) = \frac{q}{4\pi\lambda}\ln t + \frac{q}{4\pi\lambda}\ln\left(\frac{4a}{r_0^2 C}\right) \tag{1}$$

where ΔT_{id} refers to the ideal temperature rise of wire, r_0 stands for the radius of hot wire, t represents the elapsed time, q refers to the power input per unit length of wire, λ stands for the thermal conductivity of fluid, a symbolizes the thermal diffusivity of fluid, $C = 1.781 \ldots$ stands for the exponential of Euler's constant. Equation (1) demonstrates that there exists one linear relationship between ideal temperature rise and logarithm of the elapsed time t. λ, thermal conductivity is expected to be obtained by Equation (2):

$$\lambda(T, P) = \frac{q}{4\pi k} \tag{2}$$

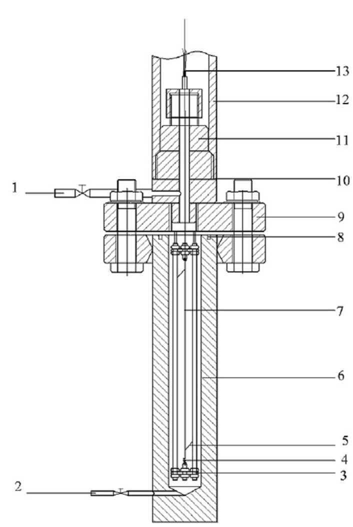
where $\lambda(T, P)$ refers to the thermal conductivity of fluid at reference temperature T in working pressure P. k stands for the slope of one line that fits temperature rise in one ideal condition compared with the logarithm of the elapsed time t, as shown in Equation (3):

$$k = \frac{\mathrm{d}(\Delta T_{\mathrm{id}})}{\mathrm{d}(\ln t)} \tag{3}$$

The principle of transient hot-wire method has been described in details with all the necessary corrections in many other papers [35–37].

2.2. Measurement system of the experiment

The liquid thermal conductivity measuremental system includes: experimental cell of thermal conductivity, data acquisition system, vacuum system, temperature measurement system and thermostatic bath. Fig. 1 is a schematic drawing of transient -hot-wire cell. The experimental cell and connected pipes is made by stainless steel. The operation temperature capability in experiment reaches up to 400 K, and the designed experimental temperature is 470 K due to the restriction of lead wires. The volume of the experimental cell was minimized to reduce the filling quantity of measured liquids and the real volume is approximately 45 ml. A 20-μm-diameter and 85-mm-long bare platinum wire was adopted in this instrument to decrease the effects because of its limited length and physical properties while remaining excellent uniformity and tensile strength, which is welded with the lower and upper platinum hooks along with one axial stress of pre-decided magnitude by hanging one copper hammer at platinum wire bottom. Moreover, two potential leads of voltage with platinum wire of the same diameter were spot-welded in positions about 10 mm away from



1.effused pipeline 2.injected pipeline 3.PTFE framework 4.spring 5.voltage lead 6.vessel 7.platinum wire 8.Cu O-ring 9.flange 10.PTFE O-ring 11.seal 12.steel cover 13.extension line

Fig. 1. Thermal conductivity experimental cell.